

The future of nuclear power and its fuel cycle

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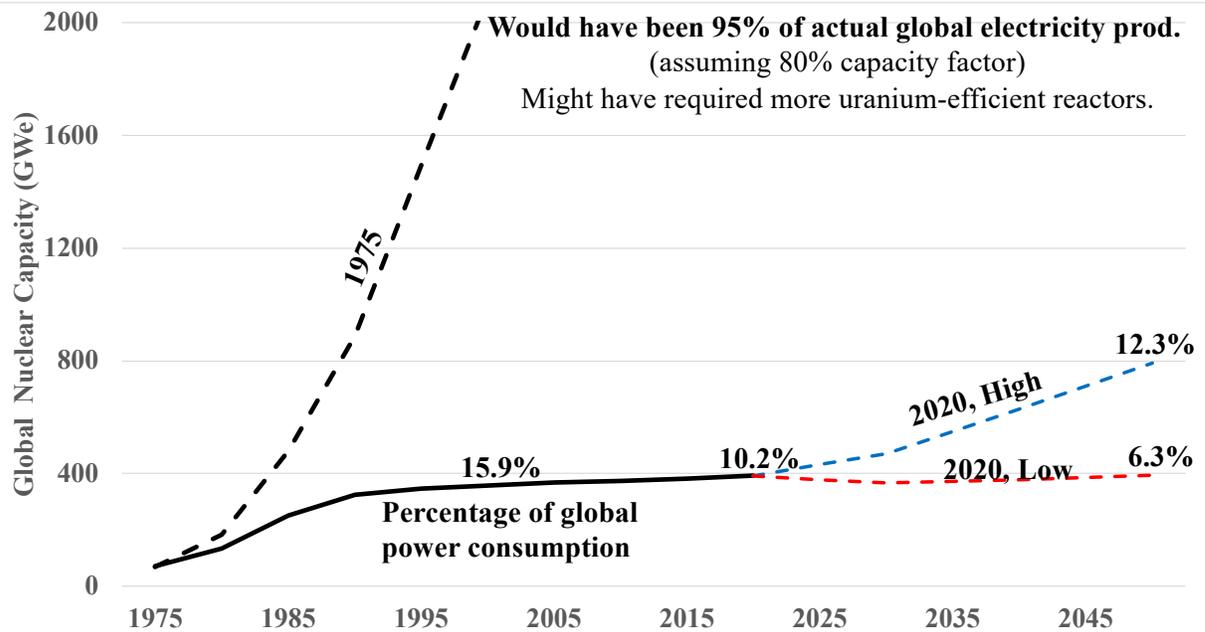
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Outline

- The uncertain future of nuclear power
- The back end: Spent fuel management
- The front end: uranium enrichment

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IAEA World Nuclear Capacity Projections in 1975 and 2021 (based on national projections)



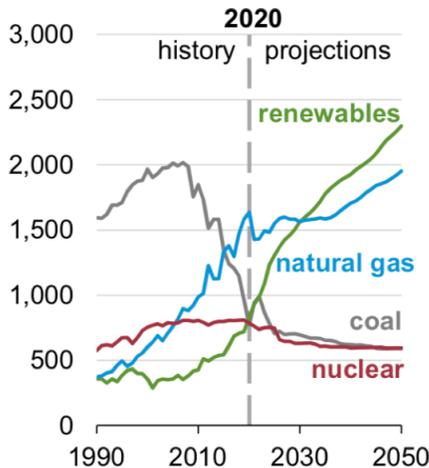
Fuel Cycle Demand, Supply and Cost Trends, <https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull18-1/18104881924.pdf>
Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, <https://www.iaea.org/publications/search/type/reference-data-series>

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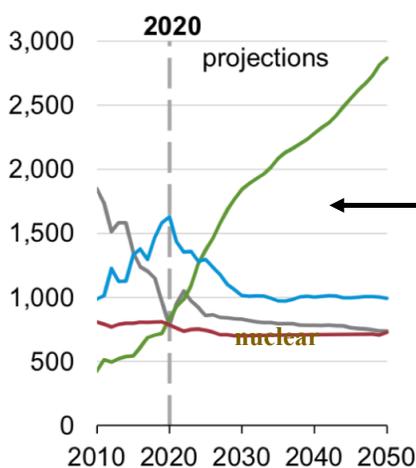
US (96 GWe with 2 GWe under construction) Projection for 2050: 2-6 GWe new, 29-14 GWe retired, 67-82 GWe life extended to 80 yrs

U.S. electricity generation, AEO2021 oil and gas supply cases

Reference case
billion kilowatthours



Low Oil and Gas Supply case
billion kilowatthours



Most climate-friendly Scenario

(gas down 1/3,
coal constant,
renewables x3
nuclear down 1/10)

Note: Renewables category includes electricity generation from wind, solar, hydroelectric, geothermal

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021 (AEO2021)*

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Small modular reactors

Original idea to create a civilian market for naval propulsion reactors.

- US: BWXT dropped out because of no customers.
- UK: Rolls Royce demands government guarantee of at least 15 reactors.

DOE funding of R&D and cost-sharing has attracted startups

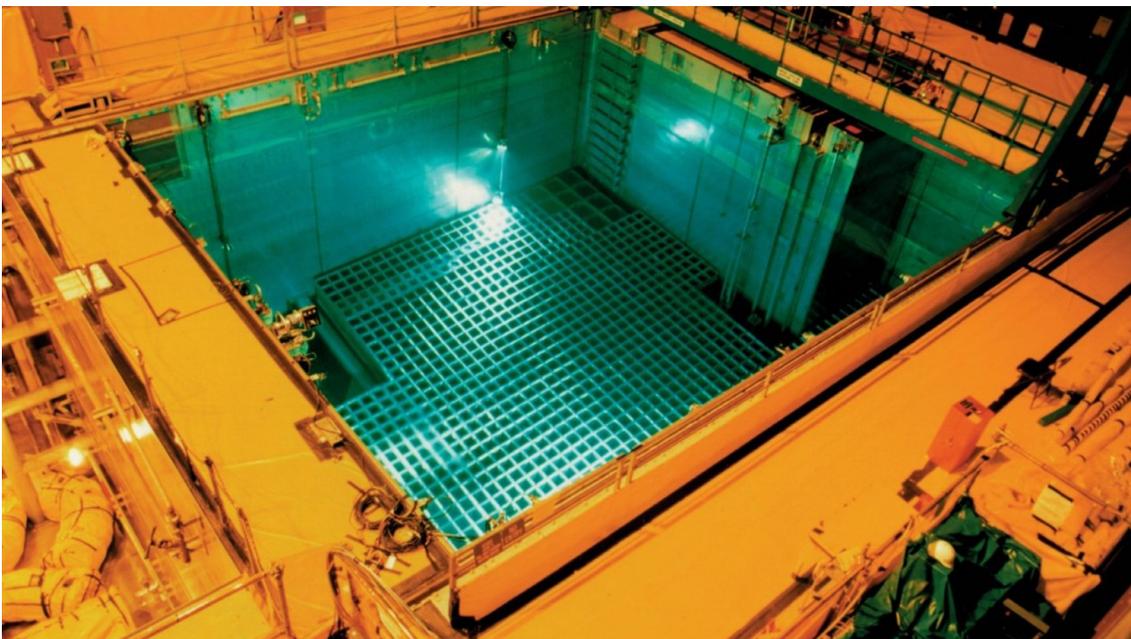
- **Water-cooled reactors** (Nuscale: Site offered at Idaho National Lab: \$0.6 billion committed by DOE for licensing process plus an additional \$1.4 billion for construction of several 0.077-GWe reactors.
- **Sodium-cooled reactors.** Designs based on Idaho National Lab's Experimental Breeder Reactor II (EBR II) shut down in 1994.
DOE proposes to match up to \$2 billion from Bill Gates, Warren Buffet et al for the 0.345-GWe *Natrium* liquid-sodium-cooled reactor in Wyoming.
- **High-temperature gas-cooled reactors.** DOE is cost matching with X-Energy for four 0.1-GWe gas-cooled reactors.

All updates of 50-year-old designs that failed to compete with large water-cooled reactors. Total capacity, if built, about equal to one the ~ 100 US large water-cooled reactors.

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Spent Fuel Management: first in pools.

Water cooling in pool for 5 (original plan) – 30 years (today). Potential for spent-fuel-pool fire if loss of water in a dense-packed pool (almost happened during Fukushima accident.)



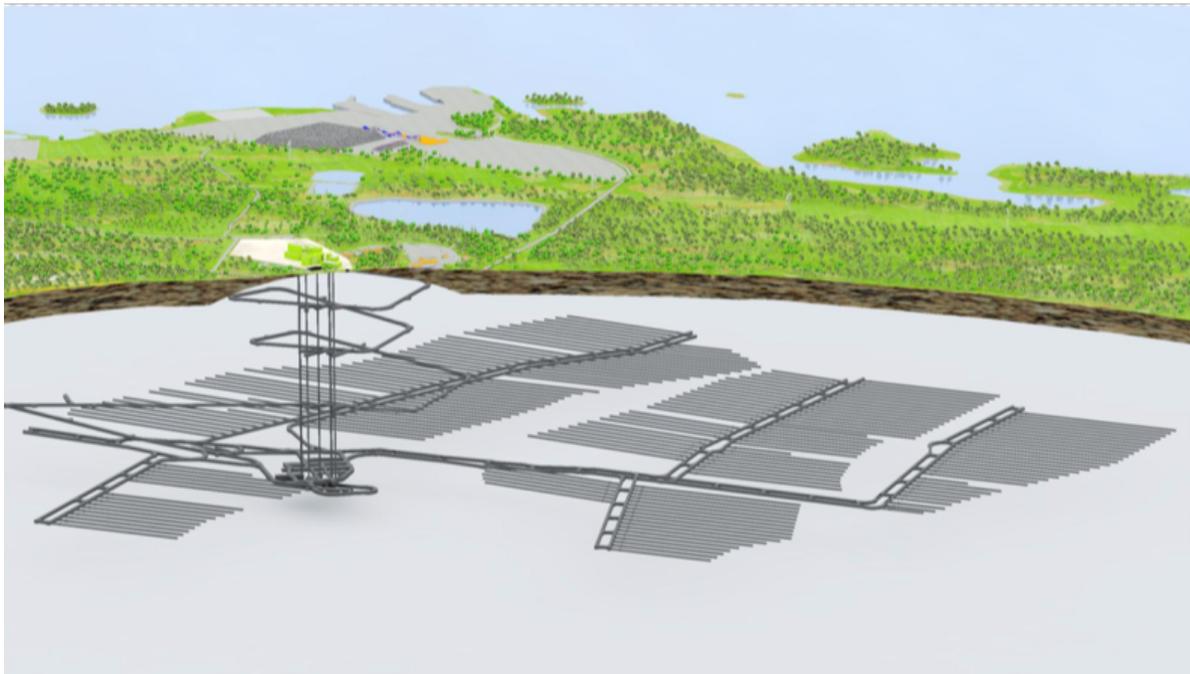
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Then storage in air-cooled casks for up to 100? Years
(all that is left on site from the Connecticut Yankee reactor)



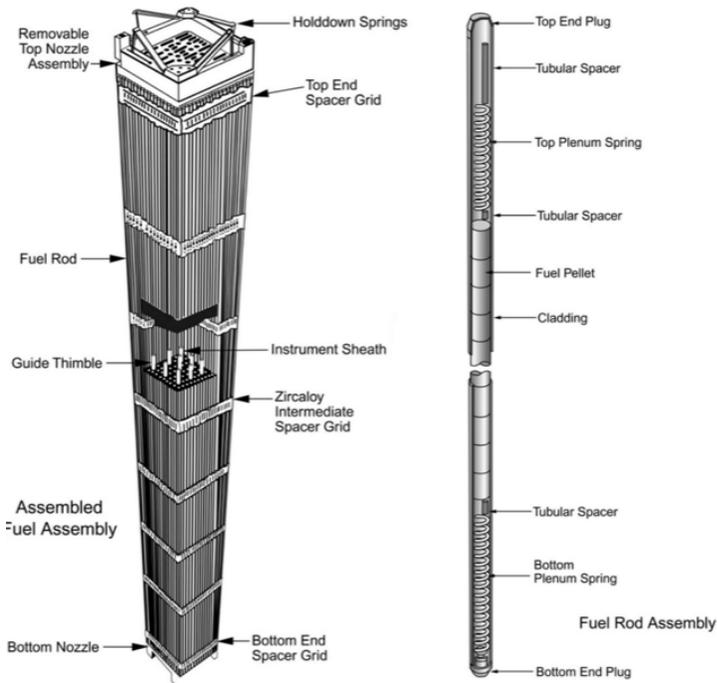
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**Ultimately to be stored in a deep-underground
(~1500 feet) repository *if a site can be found***
(Finland has a site)



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Does spent fuel have to be processed before burial?



Spent fuel from conventional water-cooled reactors does not. The fuel is in a stack of cylindrical ceramic pellets in a welded shut metal tube.

Contrary to claims, fissioning the plutonium would not reduce the hazard.

But the metal fuel developed at INL to be used by *Sodium* contains sodium, which reacts violently with water. Must be removed before burial.

INL has been struggling to process 3 tons of EBR II fuel for 20 years. Has processed only 1 ton.

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When sodium and water meet

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Uranium enrichment

- Natural uranium fuel contains only 0.7% chain-reacting uranium.
- Conventional water-cooled reactors contain 3-5 %
- Above 20% enrichment, uranium is considered weapon-usable.
- The fuel for *X-Energy*, *Natrium*, and other sodium-cooled reactors being promoted by DOE is to be close to 20% enriched.
- Such “high-assay, low-enriched uranium” is not commercially available.
- DOE is therefore advertising for suppliers who will be willing to enrich for sale uranium that is right at the limit of weapon usability.
- Is that good?

For more detail see, Ed Lyman, “*Advanced*” *Isn’t Always Better* (Union of Concerned Scientists, 2021, <https://www.ucsusa.org/resources/advanced-isnt-always-better>)